Modeling the rise of atmospheric oxygen

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The evidence for a significant change in the redox state of the Earth System approximately 2.4 Ga has become significantly stronger with the discovery of mass-independent fractionation of sulfur isotopes in Archean rocks[e.g. Farquhar 03]. However, a theoretical understanding of why this change took place between 2.45 and 2.33 Ga[Bekker et.al 04] remains elusive. Various qualitative explanations for the rise of oxygen exist in the literature, but quantitative assessments are lacking. We developed a time-dependent model that describes redox fluxes between Earth's reservoirs, which we use to test hypothesis regarding the oxygenation of Earth.

Our model solves simple differential equations which compare the sources and sinks of atmospheric oxygen and methane. The primary source of Earth's free oxygen derives from a photosynthetic biosphere, while sinks include photochemical destruction, reducing volcanic and metamorphic gases, and oxidative weathering. We drive our model with parameterizations of changing solar luminosity, biospheric activity, and hydrogen escape. We explore relevant parameter space for these fluxes and determine the first order controls on the timing of the oxygenation of Earth. We show that a reduced atmosphere can persist long after the evolution of oxygenic photosynthesis, and that the oxic transition occurs when the reducing flux from volcanic and metamorphic gases drops below the oxidizing flux from oxygen organic carbon burial, with the timing most dramatically affected by the amount of iron in the continental crust.